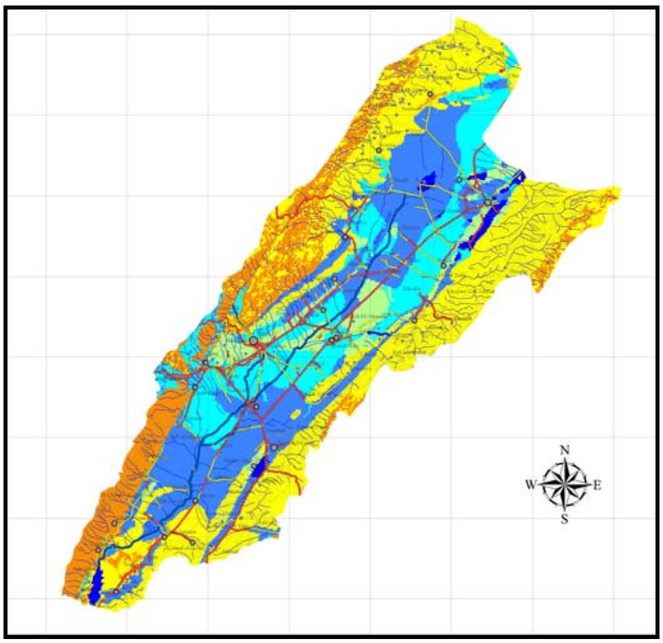
LITANI WATER QUALITY MANAGEMENT PROJECT

GROUNDWATER FLOW MODELING AND VULNERABILITY MAPPING

September 2005



LITANI BASIN MANAGEMENT ADVISORY SERVICES (BAMAS)

BUREAU FOR ASIA AND THE NEAR EAST

U.S. AGENCY FOR INTERNATIONAL DEVELOPMENT

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REPORT PREPARATION

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Table of Contents

List of Figures

Summary

A groundwater vulnerability map of Upper Litani Basin has been prepared using the DRASTIC method. DRASTIC method consists of combining seven hydrologic and hydrogeologic factors that control groundwater recharge and movement. These factors are Depth to water, net Recharge, Aquifer media, Soil media, Topography, Impact of the vadose zone media, and hydraulic Conductivity of the aquifer. The combination of the first letter of each of these parameters constitutes the acronym DRASTIC.

For each factor, the study area is subdivided into zones and attributed a rating ranging between 1 and 10, where the higher the rating, the quicker water and pollutants reach the groundwater compartment. Each factor is associated with a weight. The weighted factors are summed up to produce the vulnerability index, called the DRASTIC index.

The rating for each factors was derived from data available at various scales: geological map (scale 1:50,000), soil map (scale 1:200,000), topography (scale 1:50,000), and annual average pluviometric data available for 40 stations within and surrounding the basin. Depth to groundwater was calculated using a groundwater model based on MODFLOW. Preliminary calibration of the model was conducted based on few groundwater monitoring points and level of the river and springs.

Groundwater vulnerability analysis in Upper Litani Basin resulted in a map which illustrates areas of varying groundwater vulnerability indexes ranging from 59 to 192, where high indexes are mainly encountered on the eastern and western mountain ranges (Anti Lebanon and Mount Lebanon) mainly constituted from Jurassic and Cenomanian karstified Limestone. The quaternary deposits in the valley provide a relative cover reducing groundwater pollution potential. Nevertheless, this protecting layer did not provide enough cover to reduce infiltration of pollutants, mainly nitrates and biological pollution to the aquifer, as observed during the Winter and Summer 2005 water quality monitoring campaign conducted within the BAMAS project.

The groundwater vulnerability mapping optimizes the use of existing data to rank areas with respect to relative vulnerability to contamination. The ground water pollution potential map of Upper Litani Basin has been prepared to assist planners, managers, and local officials in evaluating the potential for contamination from various sources of pollution. This information can be used to help direct resources and land use activities to appropriate area, or to assist in protection, monitoring, and clean-up efforts.

1 Introduction

The need for protection and management of ground water resources in Upper Litani Basin is becoming an urgent necessity since a considerable percentage of Beqaa Valley inhabitants rely on ground water for drinking and household use from both public and private wells. Agriculture also utilizes significant quantities of ground water for irrigation. There is no extensive survey of groundwater wells in the Litani Basin, but in the adjacent Orontes (Aassi) more than 1500 wells were surveyed in 1997 by the Ministry of Energy and Water.

The Litani Water Quality Management Basin Advisory Services (BAMAS) Project aims at identifying and assessing management and investment options and scenarios for water quality improvement and remediation of potential pollution for the upper Litani River basin and Qaraoun Lake and developing an environmental management plan for their implementation.

As preliminary step in the environmental management plan, a vulnerability assessment should be conducted for surface and groundwater, and based on this output the environmental management plan can be established.

The purpose of this report and map is to aid in the protection of ground water resources in the Upper Litani Basin. This protection can be enhanced by understanding and implementing the results of this study, which utilizes the DRASTIC system of evaluating an area's potential for ground water pollution. The mapping program identifies areas that are vulnerable to contamination and displays this information graphically on maps. The system was not designed or intended to replace site-specific investigations, but rather to be used as a planning and management tool. The map and report can be combined with other information to assist in prioritizing local resources and in making land use decisions.

The concept of groundwater vulnerability had sometimes ambiguous definitions this why we prefer to give the definition which has been adopted by the international conference on "Vulnerability of Soil and Groundwater to Pollutants", held in 1987 in The Netherlands (Duijvenbooden and Waegeningh, 1987), as

The sensitivity of groundwater quality to an imposed contaminant load, which is determined by the intrinsic characteristics of the aquifer.

Thus defined, vulnerability is distinct from pollution risk. Pollution risk depends not only on vulnerability but also on the existence of significant pollutant loading entering the subsurface environment.

Pollution risk is defined as the result of vulnerability which is an intrinsic characteristic of the physical system multiplied by the pollution load resulting from anthropogenic influences, and sources of contamination in any given area.

In addition to the concept of groundwater vulnerability, groundwater flow pattern is very important in the definition of a catchment management plan, since the risk element should be linked to the exposed population.

Based on the above, the targets of the study are twofold:

1. Establish the groundwater flow pattern based on available data and groundwater modeling in order to link a potential risk to exposed population.
2. Establish the groundwater vulnerability map of the Upper Litani Catchment

It worth to be mentioned that this study does not pretend to provide a calibrated groundwater model, but to provide a realistic flow pattern that needs to be refined in the future in the light of the results to be collected in the proposed long term groundwater monitoring program.

2 Output

As defined above, the output of the study will consist of the following:

- A groundwater flow pattern map showing calculated groundwater levels, and flow velocity in the Upper Litani Catchment;
- A groundwater vulnerability map in respect to nitrates and phosphates established at the scale of 1/200,000.

The above mentioned products will offer valuable tools for optimizing the long term monitoring program proposed within this project, as well as excellent tool for land use and groundwater resources management planning, as explained in more details further on in this report.

3 Groundwater flow modeling

3.1 Objective

In the absence of piezometric measurements in the basin, the objective of groundwater flow modeling is to produce a first approximation of the groundwater flow pattern that will be used for:

a. Optimizing the design of the groundwater qualitative and quantitative monitoring program, proposed as a future action to the present project.
b. Assist in the groundwater vulnerability assessment proposed in the second step on the present study.

3.2 Basic Principles

Groundwater flow modeling aims at calculating hydraulic head and flow velocities within the aquifer. It is based on the resolution of the following two equations:

- Water mass balance equation
- Energy conservation equation expressed in the form of Darcy's Law.

When combined these equations result in the partial differential Boussinesq equation. This equation has to be associated to a domain, in our case it is the Upper Litani Catchment, characterized by its geographical extent and hydrodynamic characteristics (transmissivity and storativity).

The resolution of the Boussinesq equation results using numerical techniques results in calculating the piezometric level in every point of the domain, from which flow pattern and flow paths can be derived.

The geographical extent should be defined in a way to impose proper boundary conditions, either known hydraulic head or known groundwater flow, or zero-flow boundary. Below we expose the methodology used to build the mathematical model.

3.3 Conceptual geological model

3.3.1 Geological outline of the project area

The geological information is based on the following sources:

- UNDP study 1970 (Report and Hydrogeological map scale 1/200,000)
- FAO study ("Etude Hydroagricole de la Beqaa Centrale" – 1976)
- Geological map of Lebanon scale 1/50,000 – Dubertret

The Upper Litani Basin Valley is constituted by a geological depression oriented in the direction SSO-NNE, bordered from the west by the Yammouneh fault, and from the east by the Serghayah fault. To the east of the Serghayah fault, the Cenomanian outcrops on the Anti-Lebanon Range. To the south-west, the Jurassic Barouk formation outcrops in the Mount-Lebanon Range, then the Cenomanian in the north-west separated from the Jurassic by a series of transversal faults at the level of Dahr el Baidar – Chtaura (Figure 1).

Geological sections prepared by FAO (1976) are given in Appendix 1.

The majority of the Beqaa Plateau is dominated by the *Quaternary alluviums* overlaying the *Neogene Conglomeratic* formation, which in turn covers a SW-NO syncline outcropping to east and west of the Plateau with the succession of the Cenomanian-Turonian, Sennonian, and Eocene.

The *Middle Cretaceous* rocks are mainly characterized by the Cenomanian formation (C4) called also the Sannine Limestone. This formation is approximately 600 m thick (Dubertret, 1955). It is constituted of three litho-stratigraphical units. These are from bottom to top of the stratigraphical sequence: (a) the lower Cenomanian unit (C4-1) which is essentially dolomitic (Saint Marc, 1974); (b) the middle Cenomanian unit (C4-2) constituted of a limestone cliff marking the base of the unit, an alternation of beige dolomitic limestone beds (with siliceous nodules and bands) and grey dolomitic beds; and ocre to brown dolomitic, and (c) the Upper Cenomanian Unit (C4-3) entirely dolomitized to the west of the valley while it is dolomitic limestone to the east (Saint Marc, 1974).

The *Turonian Rock* formation is mainly constituted of limestone and dolomitic limestone. It is separated from the Cenomanian by a layer of marl.

The *Sennonian* outcrops along the Anti-Lebanon ridge to the South-East and from Wadi el Aarayech-Zahleh to Chmistar in the North West of the valley. The Sennonian consists of marls, limy-limestone and marly-limestone rocks.

The *Neogene* is laid unconformably of the top of the Cretaceous rocks, and followed by the *Quaternary* alluviums. The Neogene-Quaternary complex has a stratigraphic thickness that might reach 1000 m next to Damascus Road (UNDP, 1976).

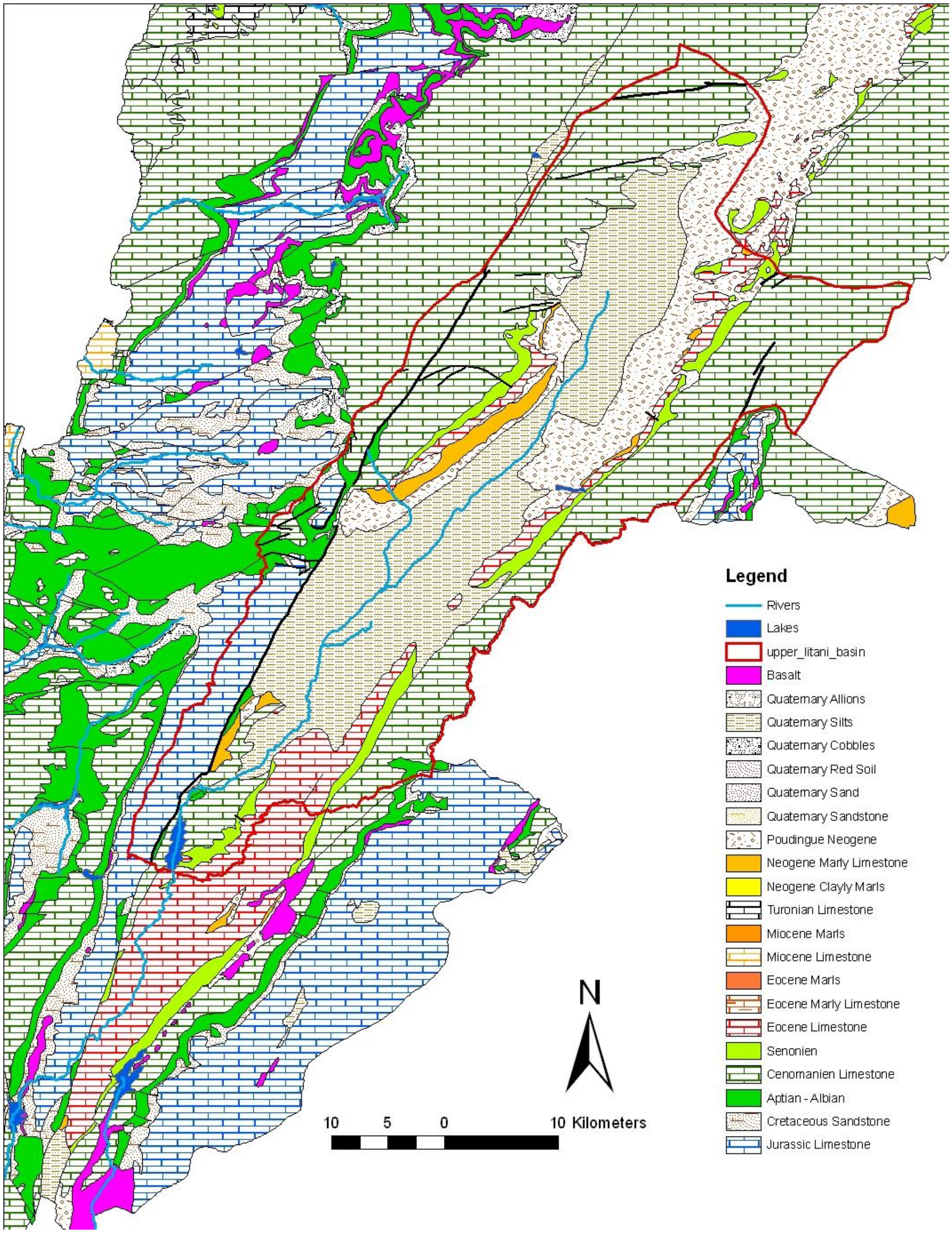

Figure 1 - Geology of the Litani Catchment

3.3.2 Hydrogeology and extent of mathematical model

Mainly six aquifers can by distinguished within the upper Litani Basin. These are:

- The limestone aquifer of the Jurassic of in the Mount Lebanon Range.
- The limestone aquifer of the Cenomanian of in the Mount Lebanon Range.
- The limestone aquifer of the Cenomanian of in the Anti-Lebanon Range.
- The limestone aquifer of the Eocene in the Mount Lebanon Range.
- The limestone aquifer of the Eocene in the Anti-Lebanon Range.
- The alluvial aquifer of the Neogene-Quaternary complex.

Some of these aquifers are interconnected. This paragraph discusses which aquifers are included in the mathematical model and the model extent.

The *Jurassic Barouk Aquifer* is mainly fed by the rain and snow pack over the Barouk Mountain. It flows towards the east where it reaches the Yammouneh fault and overflows in the form of numerous springs in Chtaura, Ammiq, Saghbine, and Kefraya, and towards the west where it feeds Mount Lebanon springs: Barouk, Re'yan, Kafra, Ammatour, etc. This aquifer is excluded from the model since it has no direct interaction with other aquifers. This aquifer overflows in the springs located along the Yammouneh fault, which in turn feed the Litani tributaries. The Yammouneh fault is considered as the western limit of the model, and is considered as a zero flow boundary.

The Mount Lebanon Cenomanian Aquifer located in the North West of the basin is interconnected below the Eocene and Quaternary to the Anti-Lebanon Cenomanian Aquifer. From both Eastern and Western boundaries of the catchment, the Cenomanian has an anticline axis which corresponds approximately to the catchment divide. This catchment divide is taken as the limit of the model as a zero flow boundary. Both the Mount Lebanon and Anti Lebanon Cenomanian aquifers are characterized by significant karstification since the observed hydraulic gradients are very low (UNDP, 1970). To the south east, the Anti Lebanon Cenomanian aquifer extends inside the Hasbani basin. This is the reason why the suggested model extends over the Hasbani basin, since the Cenomanian aquifer is common to the two basins.

The Eocene Aquifer of Mount Lebanon is of limited extent since it extends between Zahleh and Chmistar to the North-East over a distance of 18 km and an outcropping average width of 0.5 km. It is a small aquifer of 9 km^2 entirely within the Litani basin (UNDP,1976). The aquifer is formed of karstified limestone. It is included integrally within the model.

The Eocene aquifer of the Anti-Lebanon lies partly within the Upper Litani catchment partly within the Lower Litani catchment and partly within the Hasbani Catchment. It feeds the springs of Ras el Ain (Terbol), Ain Faour, Ain el Baida. The Eocene aquifer extends to the SSW to join the Mount Lebanon. The Eocene outcropping represents the divide between Litani and Hasbani Basins, but it is underlain by the Cenomanian which extends from Mount Lebanon to the Anti-Lebanon. This aquifer is included integrally within the model.

The Neogene-Quaternary aquifer corresponds practically to the aquifer lying within the Beqaa Valley with a length of 65 km within the Litani Basin and an average width of 10 km. This aquifer flows towards the South-West feeding the Eocene aquifer. It is fed from rainwater, the return flow from irrigation and the exchange with the Litani River and its tributaries.

The Jurassic Mount Hermon aquifer, although it does not belong to the Litani aquifer, it is included in the model up to the Mount Hermon crest line which also coincides with an anticline axis. This anticline axis is considered as the groundwater divide and is taken as the boundary limit of the model from the east.

To the south, based upon a previous study conducted by ARCS in 2000 entitled "*Bilan Hydrolgique du Bassin de Hasbani*" (Hydrological Balance of Hasbani Basin), groundwater flow lines practically converge towards Ouazzani spring. The flow line is considered as a zero flow boundary and the head in the vicinity of the spring is prescribed at the emergence level of the Ouazzani.

Figure 2 summarizes the boundary conditions imposed to the model.

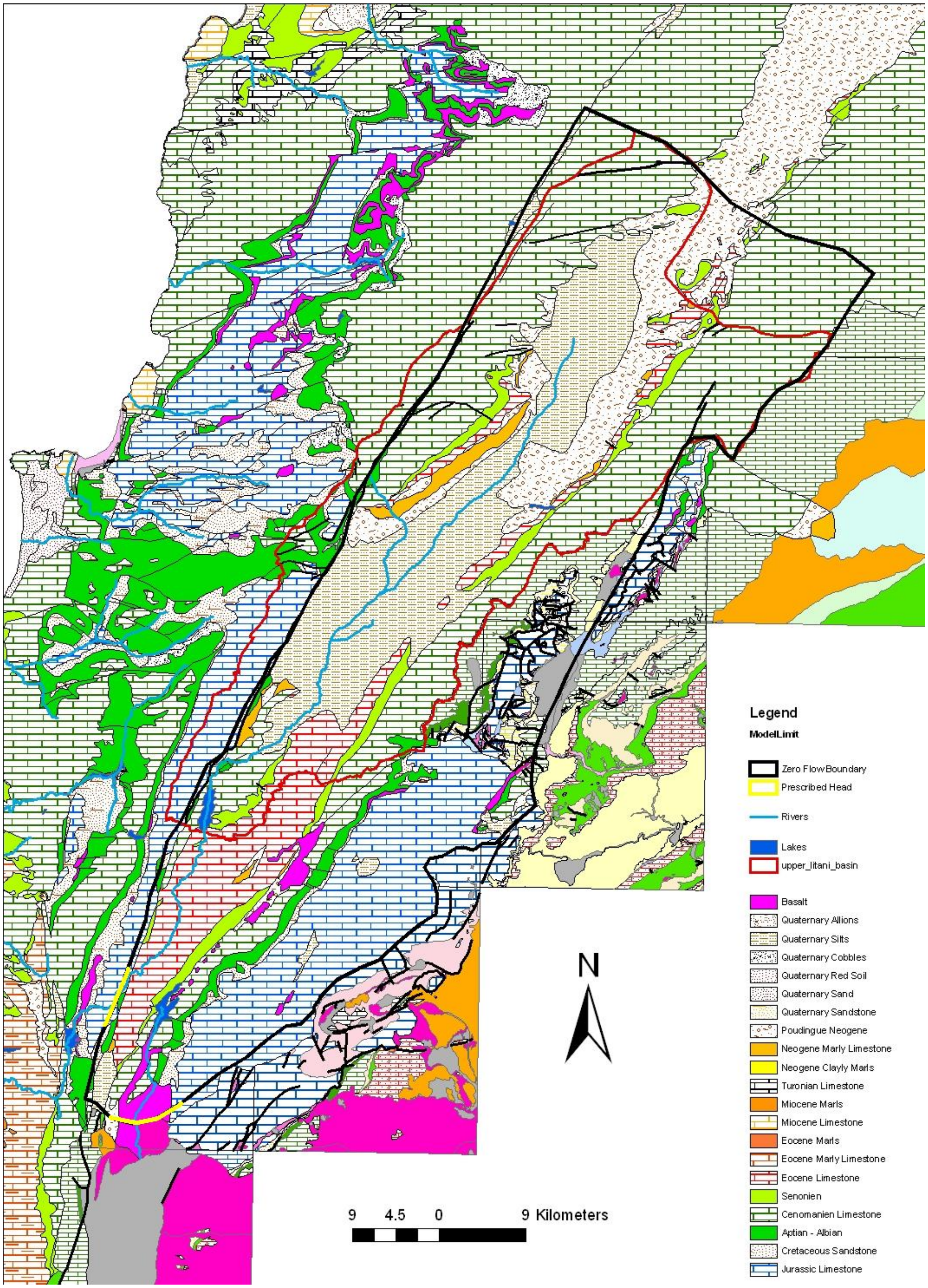

Figure 2 – Extend of the proposed groundwater mathematical model

3.4 *Source of data*

3.4.1 Hydrogeology

The Hydrogeological data, mainly hydrodynamic characteristics of the aquifers are based upon the pumping tests reported in the studies conducted by UNDP and FAO respectively in 1970 and 1976.

Groundwater levels data are merely absent over the area of the study with the exception of few wells located in the vicinity of Qobb Elias, where LRA is conducting monthly monitoring for 5 boreholes since 2001.

On the other hand, the existence of considerable number of springs is a very good indicator that can be exploited in the preliminary calibration of the model, where the level of these springs coincides with the piezometric level of the aquifer.

The hydrodynamic parameters of the aquifer (hydraulic conductivity and storativity) have been tuned keeping in mind that the final values fall within known ranges corresponding to the physical properties of the respective aquifers.

Annual groundwater abstraction flows are estimated based on the land use map and assuming that 80% of agricultural area is irrigated from groundwater and the annual demand per ha is 7000 cu.m.[1].

3.4.2 Hydrology

More than 20 rain gauge data series are available over the Upper Litani Catchment in addition to another 15 stations on the vicinity of the catchment. These stations are shown in

Figure 3.

Data has been spatially interpolated over the study area.

It has to be noted that on the Anti-Lebanon Range there is no rain gauging stations. Based upon the interpretations given by Hakim (1985), average annual rain intensity on the Mount Lebanon Range is estimated at 900 mm.

As a preliminary approximation, and based upon the FAO (1970) study, annual evapotranspiration is estimated as a function of altitude and is expressed as:

$$ETP = 450 \text{ mm} - 0.085 \cdot z$$

[1] Modern irrigation techniques - sprinklers and drippers - are widely used over the basin

Where

ETP	is annual evapotranspiration expressed in mm
z	is the elevation in meter above mean sea level

The estimated evapotranspiration rate is deduced from the precipitation. The balance is considered as groundwater recharge.

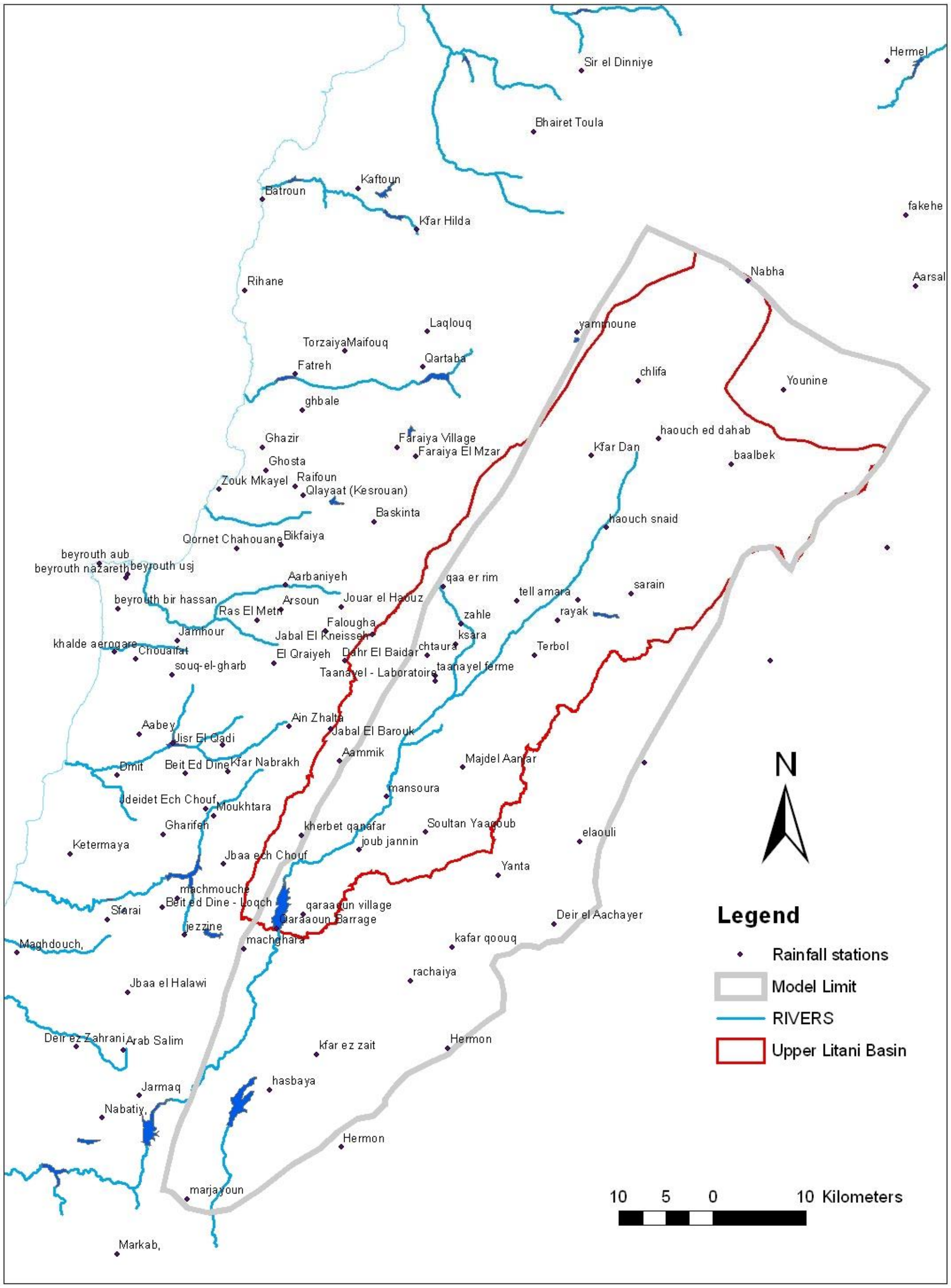

Figure 3 – Pluviometric data over the Upper Litani Catchment.

3.5 Spatial discretization

The conceptual groundwater model is translated into a finite difference mathematical model using the MODFLOW 2000 software package developed by the US Geological Survey. The MODFLOW 2000 is integrated in a user friendly environment under the commercial GMS (version 5.0) software package.

A homogeneous square 500 m x 500 m is used over the catchment.

3.6 Methodology for Preliminary Calibration

As stated earlier, the objective of the present analysis is to establish an approximate flow pattern in order to allow tracing down any pollution known its source and to provide an approximate piezometric map which represents the overtopping springs so to allow establishing a vulnerability map.

Consequently a thorough calibration is not within the scope of the project.

The model will is calibrated in a sort to reproduce the main springs located mainly in the river bed, and on the strategraphic contact between the various geological layers.

3.7 Results and discussions

The calculated piezometric levels are shown in Figure 4. The general flow pattern is oriented in the south-eastern direction almost parallel to the river axis. Two outlets are observed: one outlet towards the west at the level of Arnoun, and another outlet towards the south through the Hasbani / Ouazzani springs.

Both Litani and Hasbani basins are interconnected and the groundwater divide is different than the surface water divide.

The calculated piezometric levels are used in deriving the depth to water table in the DRASTIC method.

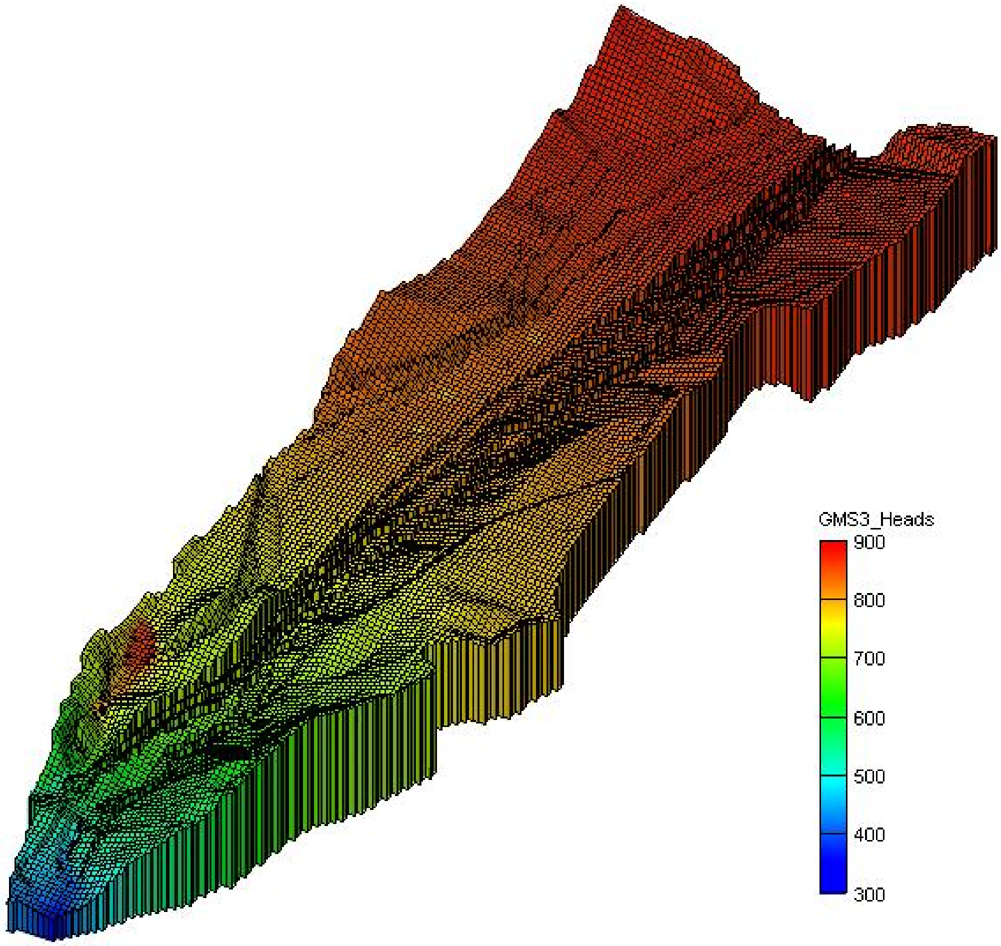

Figure 4 - Piezometric levels calculated in Upper Litani Basin

4 Groundwater Vulnerability Mapping

4.1 Applications of Groundwater Vulnerability Mapping

Groundwater Vulnerability mapping offers a wide variety of applications. The Vulnerability map of Upper Litani has been prepared to assist planners, managers, and local officials in evaluating the relative vulnerability of areas to ground water contamination from various sources of pollution. This information can be used to help direct resources and land use activities to appropriate areas, or to assist in protection, monitoring, and clean-up efforts.

An important application of the groundwater vulnerability maps for many areas will be assisting in basin land use planning and resource expenditures related to solid waste disposal, agricultural practices and allocation of lands for industrial activities. A municipality may use the map to help identify areas that are suitable for disposal activities. Once these areas have been identified, a municipality can collect more site-specific information and combine this with other local factors to determine site suitability.

Groundwater vulnerability maps may be applied successfully where non-point source contamination is a concern. Non-point source contamination occurs where land use activities over large areas impact water quality. Maps providing information on relative vulnerability can be used to guide the selection and implementation of appropriate best management practices in different areas. Best management practices should be chosen based upon consideration of the chemical and physical processes that occur from the practice, and the effect these processes may have in areas of moderate to high vulnerability to contamination. For example, the use of agricultural best management practices that limit the infiltration of nitrates, or promote denitrification above the water table, would be beneficial to implement in areas of relatively high vulnerability to contamination.

A map can assist in developing ground water protection strategies. By identifying areas more vulnerable to contamination, officials can direct resources to areas where special attention or protection efforts might be warranted. This information can be utilized effectively at the local level for integration into land use decisions and as an educational tool to promote public awareness of ground water resources. Groundwater vulnerability maps may be used to prioritize ground water monitoring and/or contamination clean-up efforts. Areas that are identified as being vulnerable to contamination may benefit from increased ground water monitoring for pollutants or from additional efforts to clean up an aquifer.

Within the local context, clean up is meant to be through non intrusive techniques by adopting appropriate management practices and land use allocation.

Stakeholders who are familiar with specific land use and management problems will recognize other beneficial uses of the groundwater vulnerability maps. Planning commissions and zoning boards within a Municipality can use these maps to help make informed decisions about the development of areas within their jurisdiction. Developers proposing projects within ground water sensitive areas may be required to show how ground water will be protected.

Regardless of the application, emphasis must be placed on the fact that the system is not designed to replace a site-specific investigation. The strength of the system lies in its ability to make a "first-cut approximation" by identifying areas that are vulnerable to contamination. Any potential applications of the system should also recognize the assumptions inherent in the system.

4.2 Methodology

4.2.1 Groundwater vulnerability mapping

Within the present study, Groundwater vulnerability mapping is based on the DRASTIC index, developed by Aller et al. (1987) for the U.S. EPA.

The index of vulnerability DRASTIC corresponds to the weighted average of 7 values corresponding to 7 hydrogeologic parameters. In the following table the DRASTIC parameters are presented together with the weights respectively for normal DRASTIC applications and for DRASTIC pesticide applications.

Table 1 - Assigned weights for DRASTIC features

Feature	**General DRASTIC Weight**	**Pesticide DRASTIC Weight**
Depth to Water	5	5
Net Recharge	4	4
Aquifer Media	3	3
Soil Media	2	5
Topography	1	3
Impact of the Vadose Zone Media	5	4
Hydraulic Conductivity of the Aquifer	3	2

These factors incorporate concepts and mechanisms such as attenuation, retardation, and time or distance of travel of a contaminant with respect to the physical characteristics of the hydrogeologic setting. Broad consideration of these factors and mechanisms coupled with existing conditions in a setting provide a basis for determination of the area's relative vulnerability to contamination.

Depth to water is considered to be the depth from the ground surface to the water table in unconfined aquifer conditions or the depth to the top of the aquifer under confined aquifer conditions. The depth to water determines the distance a contaminant would have to travel before reaching the aquifer. The greater the distance the contaminant has to travel, the greater the opportunity for attenuation to occur or restriction of movement by relatively impermeable layers.

Net recharge is the total amount of water reaching the land surface that infiltrates the aquifer measured in inches per year. Recharge water is available to transport a contaminant from the surface into the aquifer and affects the quantity of water available for dilution and dispersion of a contaminant. Factors to be included in the determination of net recharge include contributions due to infiltration of precipitation, in addition to infiltration from rivers, streams and lakes, irrigation, and artificial recharge.

Aquifer media represents consolidated or unconsolidated rock material capable of yielding sufficient quantities of water for use. Aquifer media accounts for the various physical characteristics of the rock that provide mechanisms of attenuation, retardation, and flow pathways that affect a contaminant reaching and moving through an aquifer.

Soil media refers to the upper 1.5 m (6 feet) of the unsaturated zone that is characterized by significant biological activity. The type of soil media influences the amount of recharge that can move through the soil column due to variations in soil permeability. Various soil types also have the ability to attenuate or retard a contaminant as it moves throughout the soil profile. Soil media is based on textural classifications of soils and considers relative thicknesses and attenuation characteristics of each profile within the soil.

Topography refers to the slope of the land expressed as percent slope. The slope of an area affects the likelihood that a contaminant will run off or be ponded and ultimately infiltrate into the subsurface. Topography also affects soil development and often can be used to help determine the direction and gradient of ground water flow under water table conditions.

The impact of the vadose (unsaturated) zone media refers to the attenuation and retardation processes that can occur as a contaminant moves through the unsaturated zone above the aquifer. The vadose zone represents that area below the soil horizon and above the aquifer that is unsaturated or discontinuously saturated. Various attenuation, travel time, and distance mechanisms related to the types of geologic materials present can affect the movement of contaminants in the vadose zone. Where an aquifer is unconfined, the vadose zone media represents the materials below the soil horizon and above the water table. Under confined aquifer conditions, the vadose zone is simply referred to as a confining layer. The presence of the confining layer in the unsaturated zone has a significant impact on the pollution potential of the ground water in an area.

Hydraulic conductivity of an aquifer is a measure of the ability of the aquifer to transmit water, and is also related to ground water velocity and gradient. Hydraulic conductivity is dependent upon the amount and interconnectivity of void spaces and fractures within a consolidated or unconsolidated rock unit. Higher hydraulic conductivity typically corresponds to higher vulnerability to contamination. Hydraulic conductivity considers the capability for a contaminant that reaches an aquifer to be transported throughout that aquifer over time.

The application of DRASTIC to an area requires the recognition of a set of assumptions made in the development of the system. DRASTIC evaluates the pollution potential of an area under the assumption that a contaminant with the mobility of water is introduced at the surface and flushed into the ground water by precipitation. Most important, DRASTIC is not intended or designed to replace site-specific investigations.

4.2.2 Weighting and Rating System

DRASTIC uses a numerical weighting and rating system that is combined with the DRASTIC factors to calculate a ground water pollution potential index or relative measure of vulnerability to contamination. The DRASTIC factors are weighted from 1 to 5 according to their relative importance to each other with regard to contamination potential (Table 1). Each factor is then divided into ranges or media types and assigned a rating from 1 to 10 based on their significance to pollution potential (Tables 2-8). The rating for each factor is selected based on available information and professional judgment. The selected rating for each factor is multiplied by the assigned weight for each factor. These numbers are summed to calculate the DRASTIC or pollution potential index.

Once a DRASTIC index has been calculated, it is possible to identify areas that are more likely to be susceptible to ground water contamination relative to other areas. The higher the DRASTIC index, the greater the vulnerability to contamination. The index generated provides only a relative evaluation tool and is not designed to produce absolute answers or to represent units of vulnerability. Pollution potential indexes of various settings should be compared to each other only with consideration of the factors that were evaluated in determining the vulnerability of the area.

4.2.3 Pesticide DRASTIC

A special version of DRASTIC was developed for use where the application of pesticides is a concern. The weights assigned to the DRASTIC factors were changed to reflect the processes that affect pesticide movement into the subsurface with particular emphasis on soils. Where other agricultural practices, such as the application of fertilizers, are a concern, general DRASTIC should be used to evaluate relative vulnerability to contamination. The process for calculating the Pesticide DRASTIC index is identical to the process used for calculating the general DRASTIC index. However, general DRASTIC and Pesticide DRASTIC numbers should not be compared because the conceptual basis in factor weighting and evaluation differs significantly. Table 1 lists the weights used for general and pesticide DRASTIC.

Table 2 - Ranges and ratings for depth to water

Depth to Water (m)	
Range	**Rating**
0 – 30	10
30 – 50	9
50 – 100	7
100 – 200	5
200 – 300	3
300 +	1

Weight: 5
Pesticide Weight: 5
Remark : The ranges have been adapted to the local conditions as compared to the original DRASTIC rating

Table 3 - Ranges and ratings for net recharge

Net Recharge (mm)	
Range	**Rating**
0 – 50	1
50 – 100	3
100 – 175	6
175 – 250	8
250+	9

Weight: 4
Pesticide Weight: 4

Table 4 - Ranges and ratings for aquifer media

Aquifer Media		
Range	**Rating**	**Typical Rating**
Shale	1-3	2
Glacial Till	4-6	5
Sandstone	4-9	6
Limestone	4-9	6
Sand and Gravel	4-9	8
Interbedded Ss/Sh/Ls/Coal	2-10	9
Karst Limestone	9-10	10

Weight: 3
Pesticide Weight: 3

Table 5- Ranges and ratings for soil media

Soil Media	
Range	**Rating**
Thin or Absent	10
Gravel	10
Sand	9
Peat	8
Shrink/Swell Clay	7
Sandy Loam	6
Loam	5
Silty Loam	4
Clay Loam	3
Muck	2
Clay	1

Weight: 2
Pesticide Weight: 5

Table 6 - Ranges and ratings for topography

Topography (percent slope)	
Range	**Rating**
0-2	10
2-6	9
6-12	5
12-18	3
18+	1

Weight: 1
Pesticide Weight: 3

Table 7 - Ranges and ratings for impact of the vadose zone media

Impact of the Vadose Zone Media		
Range	**Rating**	**Typical Rating**
Confining Layer	1	1
Silt/Clay	2 – 6	3
Shale	2 – 5	3
Limestone	2 – 7	6
Sandstone	4 – 8	6
Interbedded Ss/Sh/Ls/Coal	4 – 8	6
Sand and Gravel with Silt and Clay	4 – 8	6
Glacial Till	2 – 6	4
Sand and Gravel	6 – 9	8
Karst Limestone	8 – 10	10

Weight: 5
Pesticide Weight: 4

Table 8 - Ranges and ratings for hydraulic conductivity

Hydraulic Conductivity		
Range (GPD/FT^2)	**Range (m/s)**	**Rating**
1-100	10^{-7} – $5x10^{-5}$	1
100-300	$5x10^{-5}$ – $1.5x10^{-4}$	2
300-700	$1.5x10^{-4}$ – $3x10^{-4}$	4
700-1000	$3x10^{-4}$ – $5x10^{-4}$	6
1000-2000	$5x10^{-4}$ – 10^{-3}	8
2000+	$> 10^{-3}$	10

Weight: 3
Pesticide Weight: 2

4.3 Factors Selection

4.3.1 Depth to Water

This factor was evaluated using information from the groundwater flow model.

It is worth noting that the groundwater flow model has not been calibrated against site measurements, but only using the available data from the limited number of boreholes monitored by LRA and the estimated piezometric levels deduced from springs' levels.

Depth to water ranged between 0 (in the vicinity of springs and the lake) and 300 m or more in the mountain ranges, accordingly, rating ranged between 0 and 10 as indicated in Figure 5.

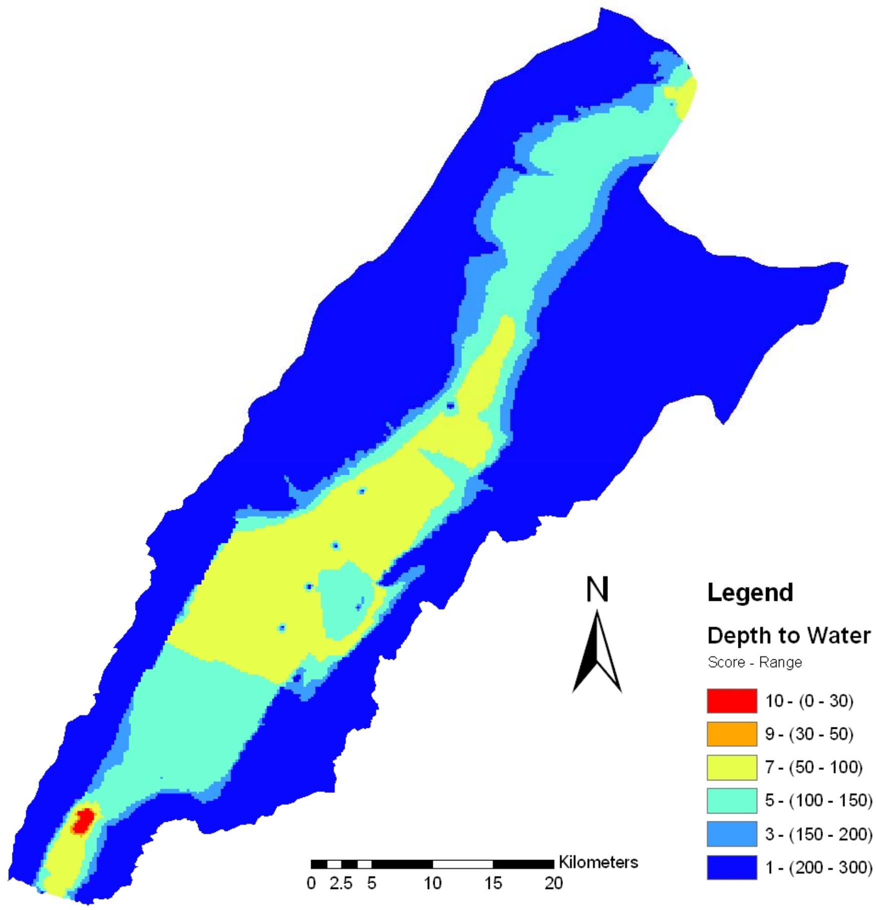

Figure 5 - DRASTIC rating for Depth to Water

4.3.2 Net Recharge

Net recharge is the precipitation that reaches the aquifer after evapotranspiration and runoff. This factor was evaluated using two criteria: (i) annual precipitation as spatially interpolated from available measurements, and (ii) evapotranspiration as derived from the empirical formulae derived by FAO within the Beqaa Valley context as mentioned in paragraph 3.4.2.

DRASTIC rating for Net Recharge is shown in Figure 6.

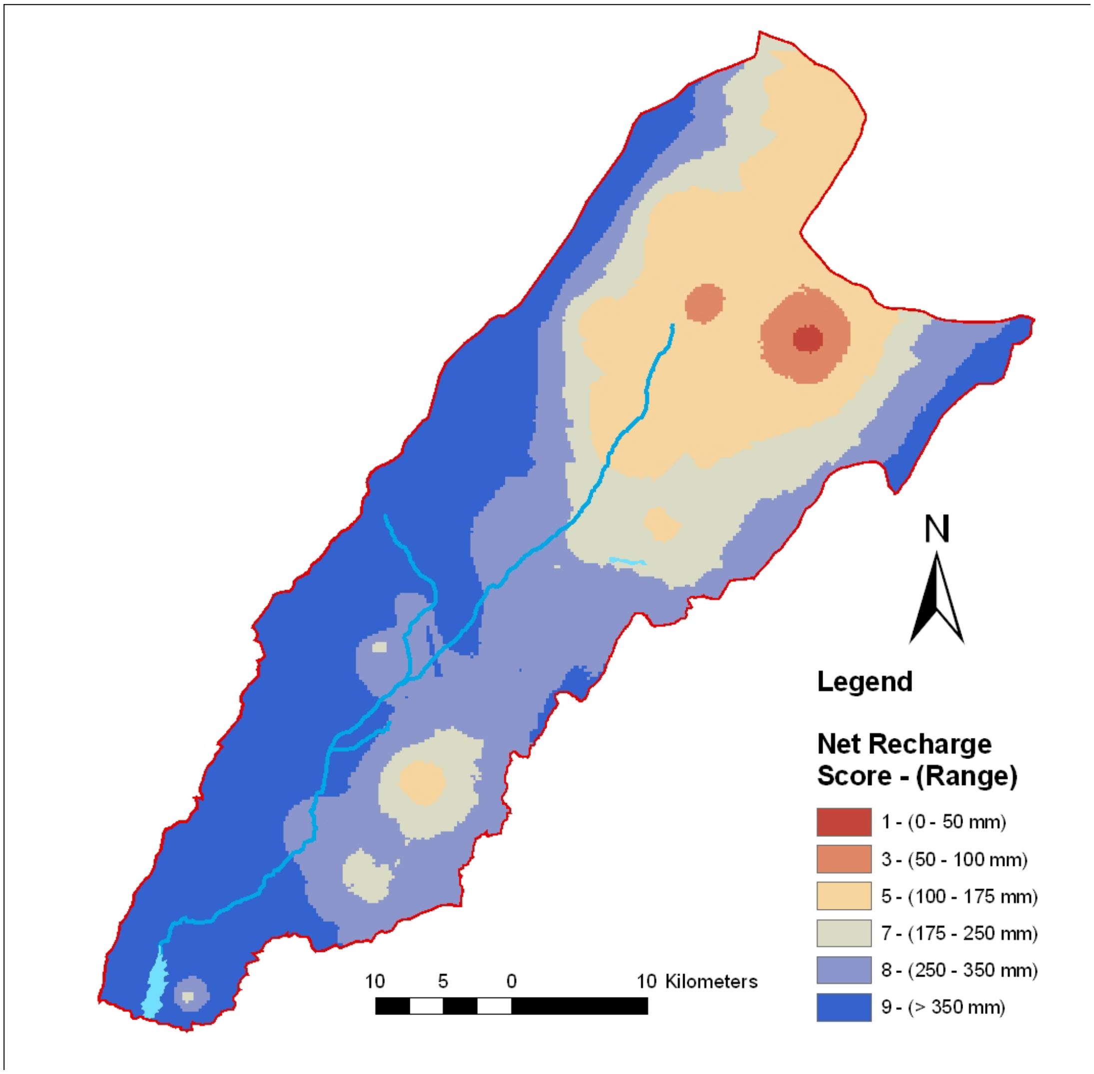

Figure 6 - DRASTIC rating for Net Recharge

4.3.3 Aquifer Media

Information on evaluating aquifer media was obtained primarily from the Geological Map of Lebanon established by Dubertret (1965?) at the scale 1/50,000 and revisited by the UNDP in 1970 at the scale 1/200,000. The UNDP Hydrogeological Map was an important source of aquifer data.

All of the limestone and sandstone bedrock are semiconfined or leaky; however for the purposes of DRASTIC, they have been evaluated as being unconfined (Aller et al., 1987). An aquifer rating of (8) was applied to Cenomanian limestone in the northwestern and eastern mountain ranges. A rating of (9) was applied to the Jurassic limestones that comprise the aquifer in south western part of the Basin. These rocks were evaluated as having more solution features and more subject to karstification. A rating of (6) was attributed to the interbedded marly limestone of the Eocene.

An aquifer rating of (5) for sandstone and interbedded Sandstone+Shale was used for the Aptian/Albian formation. An aquifer rating of (5) was used for the silty deposits of the Quaternary in the valley. The clayly-marls of the Neogene were attributed an aquifer rating of (2) for their poor permeability.

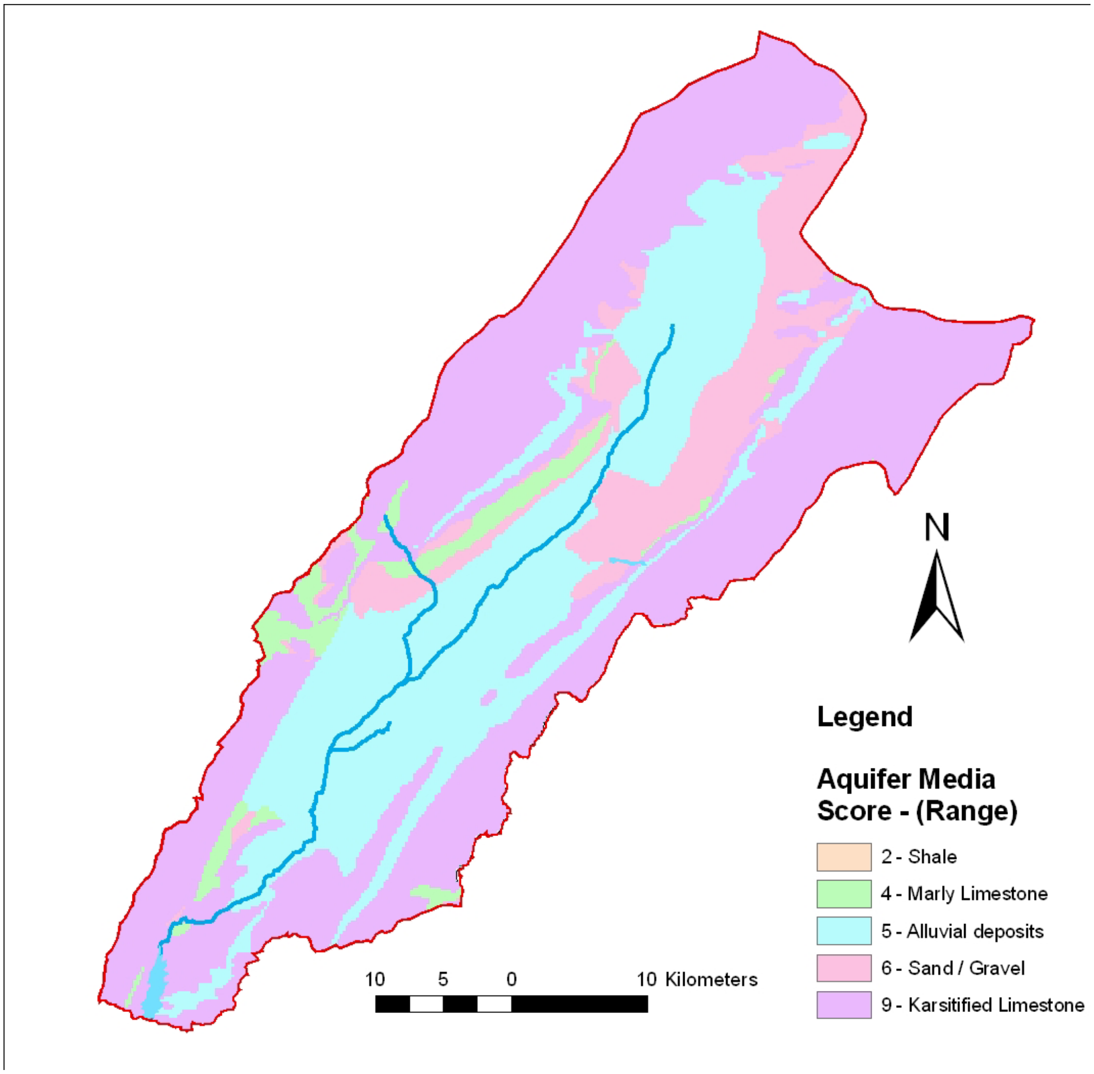

Figure 7 - DRASTIC rating for Aquifer Media

4.3.4 Soils

Soils were mapped using the data obtained from the Geological Map of Lebanon (Dubertret), and the information taken from the FAO study (1976). Evaluations were based upon the texture, permeability, and shrink-swell potential for each soil material. Special emphasis is placed upon determining the most restrictive layer.

The soils of Litani Basin show a high degree of variability. This is a reflection of the parent material.

Figure 8 shows the allocation of Soil Media rating for the Upper Litani Basin.

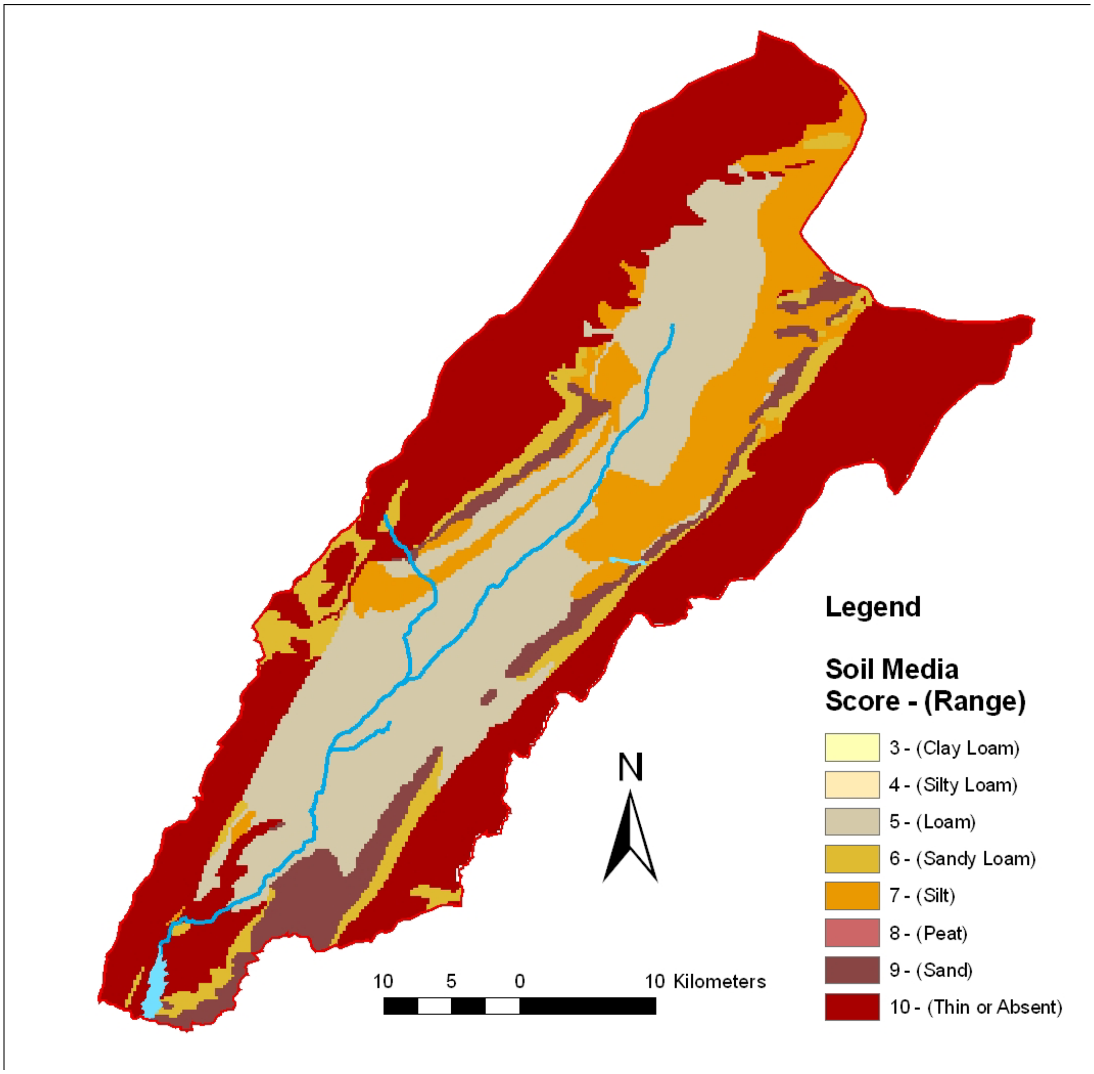

Figure 8 - DRASTIC rating for Soil Media

4.3.5 Topography

Topography, or percent slope, was evaluated using 1/200,000 topographic map of Lebanon. Slopes of 0 to 2 percent (10) were selected for almost all of the central area of the basin due to the overall flat lying to gently rolling topography and low relief. Slopes of 2 to 6 percent (9) were assigned to the northeastern and northwestern sides of the valley. Slopes of 12 to 18 percent (3) and 18 and above (1) were selected for the mountainous ranges.

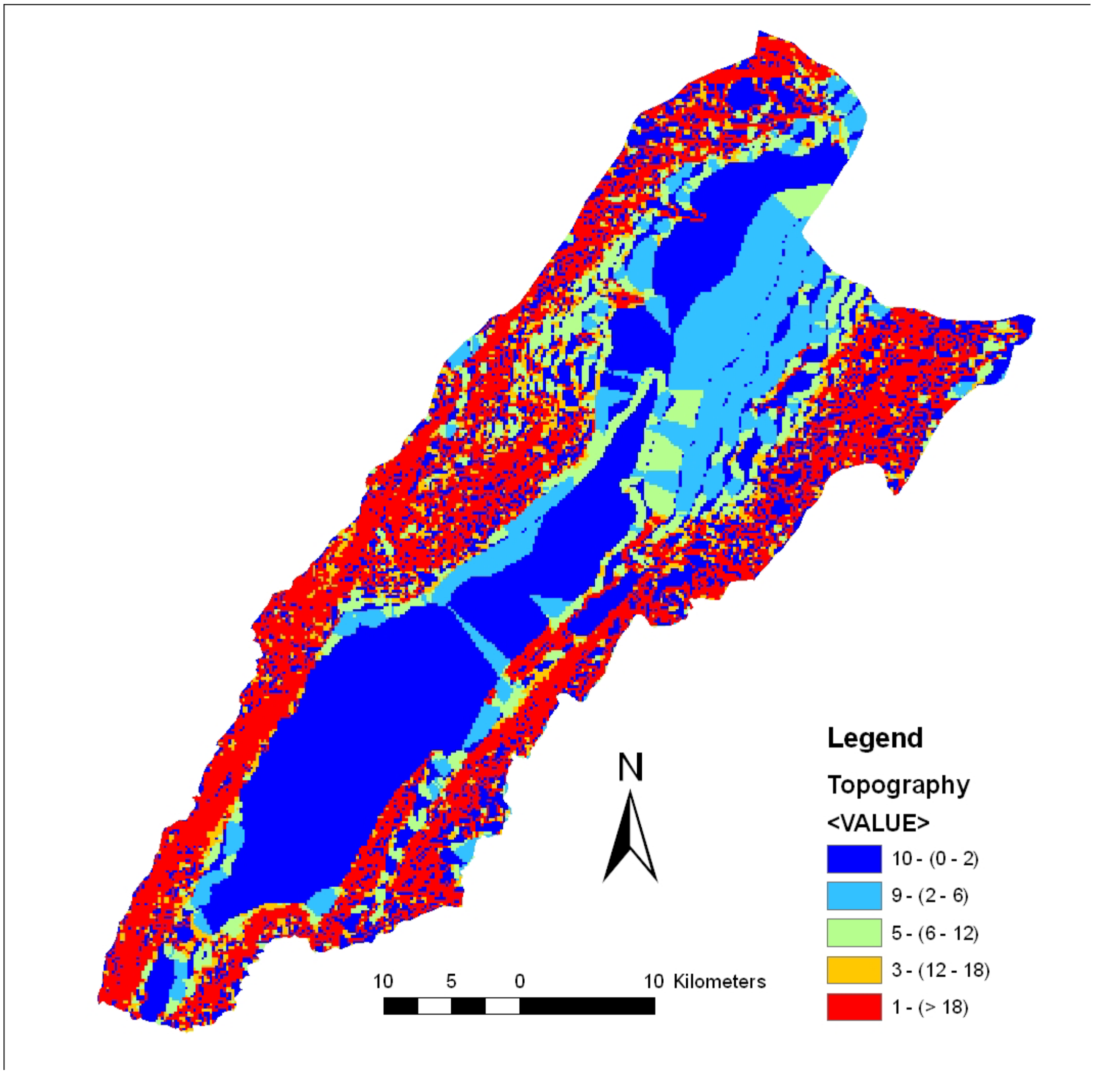

Figure 9 - DRASTIC rating for Topography

4.3.6 Impact of the Vadose Zone Media

Information on evaluating vadose zone media was obtained primarily from the *"Etude Hydroagicole de la Beqaa Centrale"* (FAO, 1976) and the geological map of Lebanon (Dubertret, 19xx).

The vadose zone media is a critical component of the overall DRASTIC rating in the Upper Litani Basin. The rating varies with the restrictive properties of the various geological formations. The higher the proportion of silt and clay and the greater the compaction (density) of the sediments, the lower the permeability and the lower the vadose zone media are rated.

Karst Limestone with a rating of (10) was attributed to Jurassic and Cenomanian formations. A rating of (8) was associated to the Eocene limestone formation. Sand and Gravel with a rating of (6) was selected as the vadose zone material for alluvial deposits in the cones of dejection on the mountain sides. Silt and Clay with a rating of (3) was selected for the silty red soil quaternary deposits in the middle of the valley.

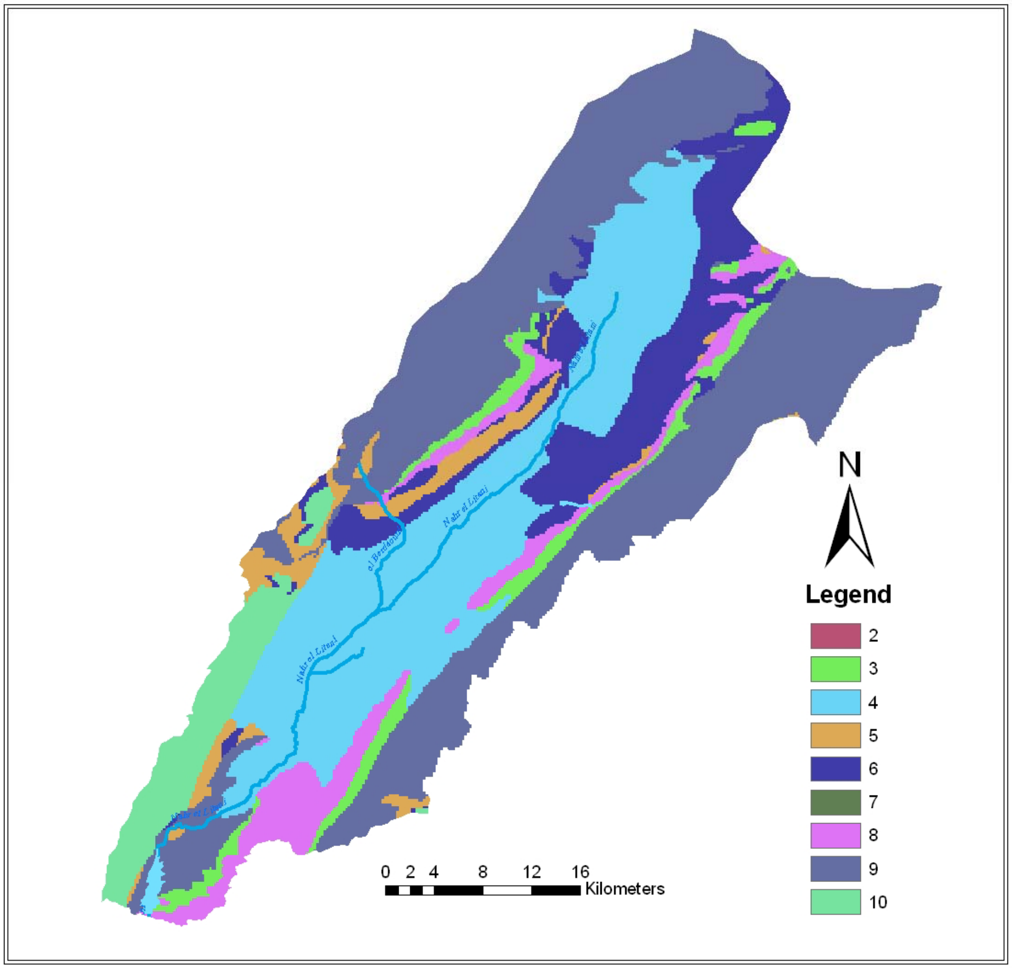

Figure 10 - DRASTIC rating for the Impact of the Vadose Zone

4.3.7 Hydraulic Conductivity

Information on evaluating the hydraulic conductivity was obtained from the Hydrogeological Map of Lebanon established by the UNDP (1970) in addition to the groundwater model established within this study.

Values for hydraulic conductivity correspond to aquifer ratings; i.e., the more highly rated aquifers have higher values for hydraulic conductivity. All of the sand and gravel aquifers with an aquifer rating of (6) have been given a hydraulic conductivity rating of $1.5x10^{-4}$ – $3x10^{-4}$ m/s. Sand and gravel aquifers with an aquifer rating of (5) were assigned a hydraulic conductivity range of $5x10^{-5}$ – $1.5x10^{-4}$ m/s (2). These ratings reflect the overall fine-grained nature of these sands and the presence of fines.

Jurassic and Cenomanian limestone aquifers with high conductive media ($5x10^{-4}$ – 10^{-3} m/s) were assigned a rating of (8) and (9) respectively. The Jurassic tends to have a higher degree of solution and secondary porosity. The other limestone aquifers were given a hydraulic conductivity of $1.5x10^{-4}$ – $3x10^{-4}$ m/s (4). The sandstone, interbedded Sandstone+Shale, and shale aquifers were assigned a hydraulic conductivity rating of (1) 10^{-7} – $5x10^{-5}$ m/s.

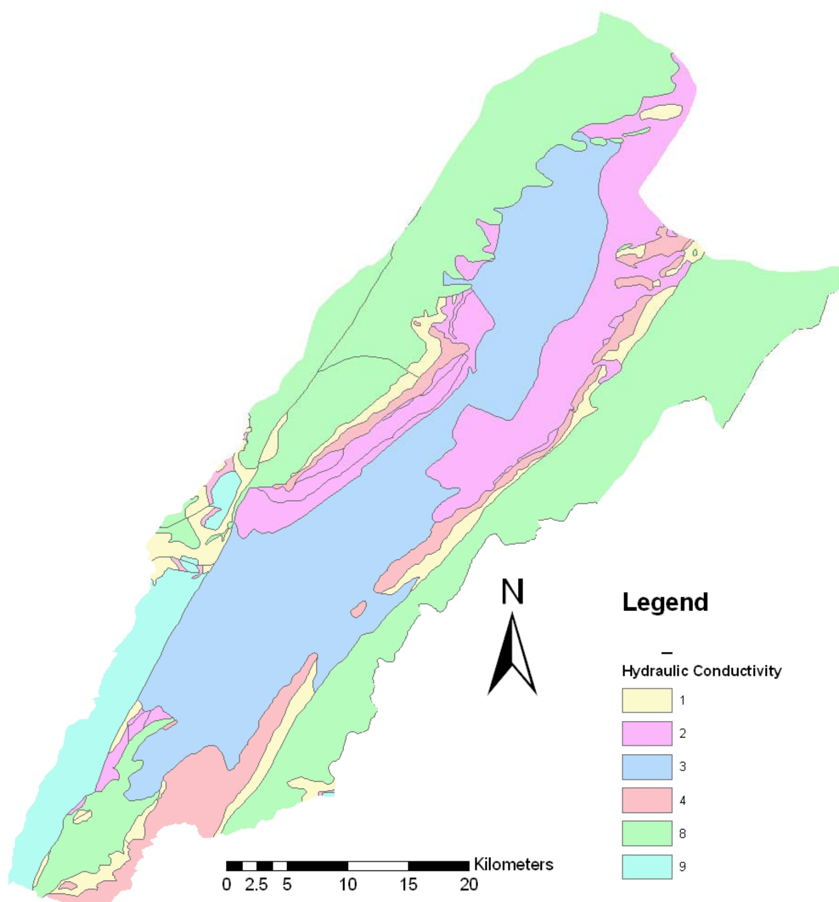

Figure 11 - DRASTIC rating for Hydraulic Conductivity

4.4 Results

The combination of the various DRASTIC indices leads to the derivation of the vulnerability map given in Appendix 1.

DRASTIC vulnerability indexes ranged between 59 and 219, where higher indexes are encountered on the Mount Lebanon and Anti Lebanon mountain ranges formed mainly of karstified limestone (Jurassic and Cenomanian).

The Beqaa Valley is covered by quaternary alluviums with deep soil, and of lower permeability, thus providing a protective layer to the underlying aquifers. Nevertheless, Winter and Summer groundwater quality survey campaigns conducted within the BAMAS project showed that substantive agricultural and biological pollution is reaching the aquifers, mainly nitrates, feacal and total coliforms, which indicates that a high pollution load on the surface is affecting the aquifer.

Considerable efforts should be deployed in order to reduce the pollution pressure on the surface. In this regard two major axes should be targeted: collection and treatment of domestic wastewater on the one hand, and reduction of agricultural pollution on the other hand through an optimization of the use of fertilizers.

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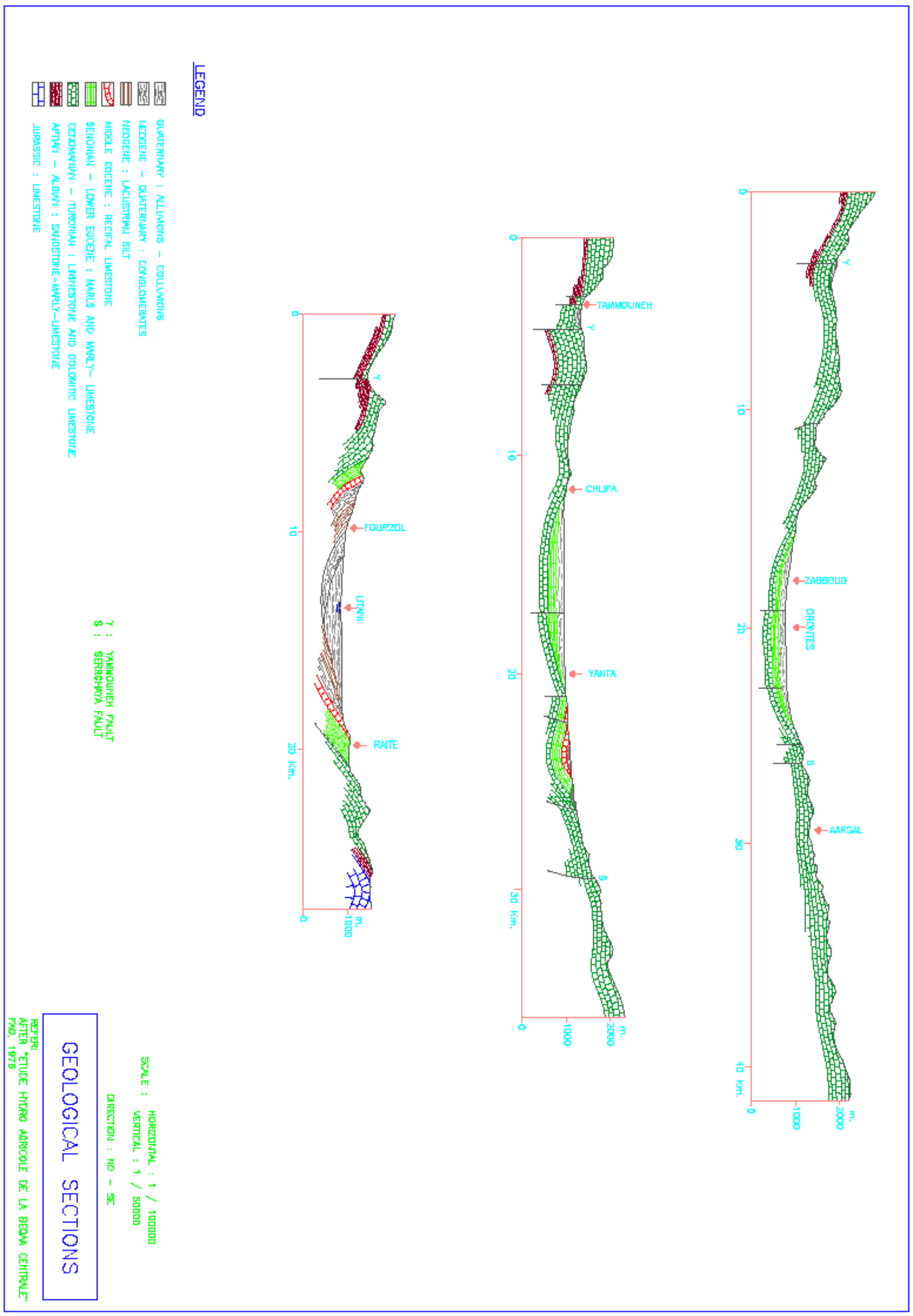
APPENDIX 1 – GEOLOGICAL SECTIONS



APPENDIX 2 – GROUNDWATER VULNERABILITY MAP